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EROSIVITY OF A NITRAMINE PROPELLANT

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To achieve extended ranges with lightweight guns, the Army uses propellants with flame temperatures greater than 3000K. Such propellants erode gun steel, leading to undesirably short wear lives. One solution to this problem is development of propellants with comparable performances and lower flame temperatures. Nitramine-containing propellants offer such possibilities, but previous experiments indicated the nitramine propellants were more erosive than conventional propellants. In view of the need for high-force,low-flame temperature (Cont'd)

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propellants, it was important to re-examine the earlier unexpected results. A series of experiments was conducted in a 37mm blow-out gun with a high impetus nitramine propellant containing 37-percent RDX and four standard Army propellants: M1, M30, M5, and M8. The nitramine propellant has a flame temperature about the same as M5 and an impetus slightly greater than M8 propellant. The erosivities of the five propellants were measured by mass loss of a contoured nozzle. A radioactive technique was also used which measured the amount of wear of the contoured nozzle. Most experiments were carried out at blow-out chamber peak pressures of 193 MPa (28 kpsi) with additional experiments at 283 MPa (41 kpsi) and 413 MPa (60 kpsi). The results show the erosivity of the nitramine propellant to be even less than that of M5, and considerably less than that of M8. A correlation is shown for erosivity as measured by the rate of mass loss and as measured by the rate of wear by the radioactive technique.

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I. INTRODUCTION

Three extended-range howitzers have recently been developed for Army deployment. To meet the extended-range requirements, the propellant charge, chamber pressure, and projectile muzzle velocity were increased for each. The top zones of the propellant charges consist of M30 propellant while the lower zones consist of M1 propellant. M30 propellant has a higher impetus and flame temperature than M1. The combined effects of the changes in the propellant charge for extended-range led to the new howitzers being wear limited rather than fatigue limited as was the case for the previous generation of howitzers. In addition, the wear lives of the new howitzers were less than the wear lives predicted at the start of engineering development. This situation is displayed graphically in Figure 1.

One way to increase the wear lives of both the extended-range howitzers and future tank cannons is to develop and use propellants with an impetus similar to, but with flame temperatures lower than M30. One approach to this end is to use the crystalline nitramine compounds, RDX or HMX, as ingredients in propellants. Such propellants have been referred to as nitramine propellants.

The nitramine propellants generally have a higher impetus and lower flame temperature than standard Army propellants. To illustrate these features, the BLAKE gun propellant thermodynamic code[1] was used to compute the impetus, flame temperature, and other parameters of interest, for a series of propellant compositions. The compositions studied were nitrocellulose-nitroglycerin (NC/NG) as a reference, nitrocellulose-RDX (NC/RDX), and polyurethane-HMX (PU/HMX). Figure 2 is a plot of impetus and flame temperature vs. composition, where BI is the binder content, either NC or PU, and OX is the oxidizer content, either NG, RDX, or HMX. Comparing the NC/NG and NC/RDX systems, the impetus for NC/RDX continues to increase as the oxidizer content increases, while the impetus for the NC/NG system reaches a maximum and then decreases. The impetus for the NC/RDX system is comparatively high for large oxidizer content. The flame temperature for the NC/RDX system is always less than that for the NC/NG system. Using HMX as the oxidizer, the impetus and flame temperature are essentially the same as with RDX.

The PU/HMX system is a formulation studied in the Army's Low Vulnerability Ammunition Program (LOVA)[2]. Only the impetus has been

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1. *E. Freedman, "BLAKE - A Ballistic Thermodynamic Code Based on TIGER", Proceedings of the International Symposium on Gun Propellants, Picatinny Arsenal, New Jersey, October 1973.*

2. *J.J. Rocchio, H.J. Reeves, I.W. May, "The Low Vulnerability Ammunition Concept -- Initial Feasibility Studies", Ballistic Research Laboratories Memorandum Report No. 2520, August 1975, AD #B0065854L.*

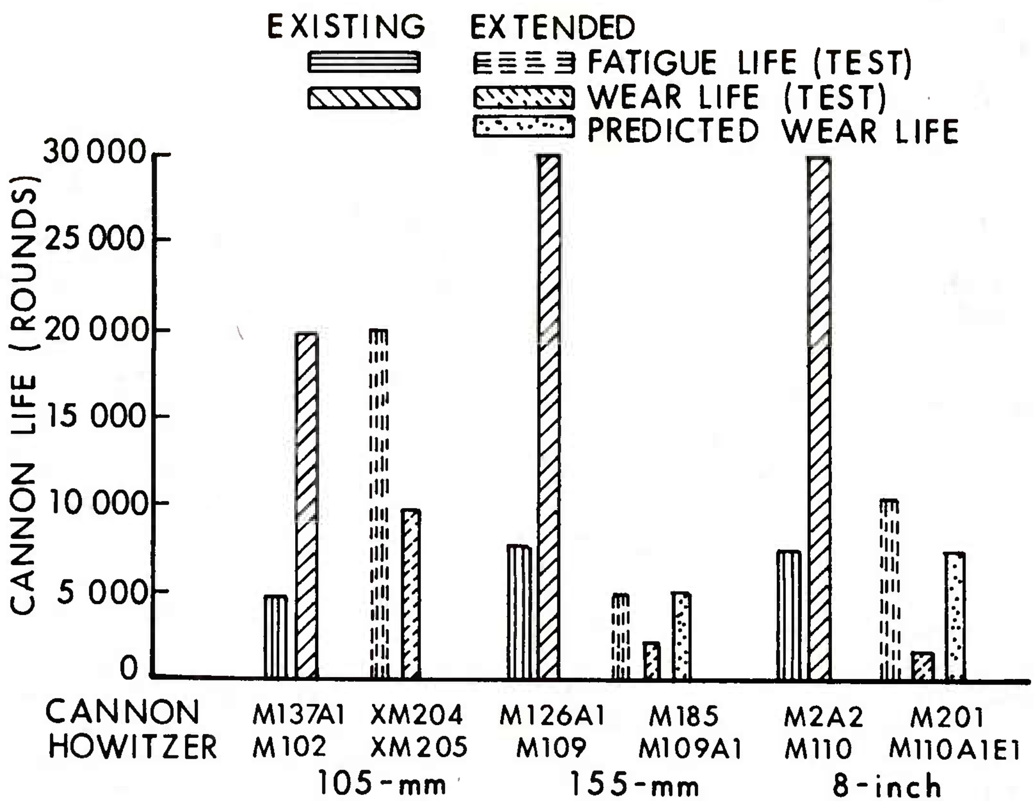

Figure 1. Comparison of Tube Life for Existing Cannons and Extended Range Cannons

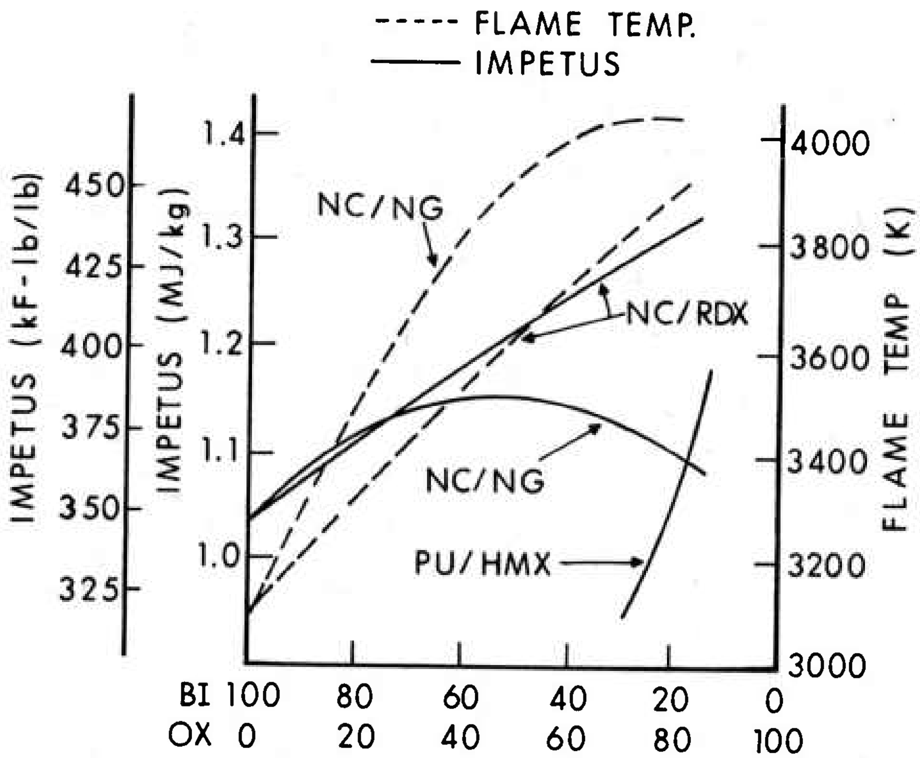

Figure 2. Impetus and Flame Temperature vs. Composition

plotted in Figure 2, the flame temperature being below the scale of the plot. The PU/HMX formulation yields a comparatively moderate impetus with a corresponding low flame temperature. For a 25/75 percent by weight PU/HMX composition, the flame temperature is 2170 K and at 15/85 percent by weight PU/HMX, the flame temperature is 2840 K. Because the polyurethane binder is inert, one would expect the impetus and flame temperature to be less than that for the energetic binder system.

A review of results from past erosivity experiments with nitramine propellants[3-5] indicates they are more erosive than standard Army propellants with comparable flame temperatures. In view of the need for new high-force, low-flame temperature propellants, it was important to re-examine the erosivity of nitramine propellants. Erosivity tests were performed in a 37mm blow-out gun with a high-force nitramine propellant and four standard Army propellant compositions: M1, M30, M5, and M8. The high force propellant (HFP) was prepared by the USA ARRADCOM Large Caliber Weapon Systems Laboratory at Dover, New Jersey.

II. EXPERIMENTAL

The study was conducted to compare the erosivities of HFP and standard Army propellants M30, M1, M5, and M8. The compositions, thermochemical properties, and grain dimensions are shown in Tables I and II. The M8 propellant was selected for its high impetus, about that of HFP, but with a higher flame temperature. The M5 propellant was selected for its flame temperature, similar to HFP, but with an impetus less than HFP. The M30 propellant was selected because it is used in artillery and tank guns where wear and erosion are a problem. The M1 propellant was selected as a representative of low flame temperature and low impetus propellants.

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3. *"Hypervelocity Guns and the Control of Gun Erosion", Summary Technical Report of Division 1, NDRC, Vol. 1, Washington, DC, 1946.*

4. *J.P. Picard and R.L. Trask, "The Effect of Propellant Ingredient Functional Groups on Gun Barrel Erosion and a Search for More Effective Additives for Reducing Erosion", Proceedings of the International Symposium on Gun Propellants, Picatinny Arsenal, New Jersey, October 1973.*

5. *E.F. Bozza, B.A. Lehman, and R.P. Baumann, "High Force - Low Temperature, Nitramine Filled Propellants", Proceedings of the International Symposium on Gun Propellants, Picatinny Arsenal, New Jersey, October 1973.*

TABLE I. Compositions, Thermochemical Properties, and Grain Dimensions of M30 and HFP Propellants

	M30 PPL-A-6372	HFP PPL-A-6380
Nitrocellulose (12.6%N)	28.0%	29.3%
Nitroglycerin	22.5	22.7
Nitroguanidine	47.7	5.0
RDX		36.5
Dioctylphthalate		5.0
Ethyl Centralite	1.5	1.5
Cryolite	0.3	
Total Volatiles (Residual)	(0.2)	(0.3)
Impetus (MJ/kg)	1.088	1.179
Flame Temperature (K)	3040.	3255.
Covolume (m^3/kg)	1.057×10^{-3}	1.069×10^{-3}
Ratio of Specific Heats	1.238	1.243
Molecular Wt. Gases	23.21	23.08
Grain Length (mm)	7.78	10.58
Grain Diameter (mm)	1.59	2.37
Grain Perf. Diameter (mm)	0.46	0.77
Grain Web (mm)	0.56	0.80
Grain Geometry	SP	SP

TABLE II. Compositions, Thermochemical Properties, and Grain Dimensions of M5, M8, and M1 Propellants

	M5	M8	M1
Nitrocellulose	81.95%	52.15%	85.00%
(Percent Nitrogen)	(13.25)	(13.25)	(13.25)
Nitroglycerin	15.00	43.00	
Ethyl Centralite	0.60	0.60	
Barium Nitrate	1.40		
Potassium Nitrate	0.75	1.25	
Diethylphthalate		3.00	
Dinitrotoluene			10.00
Dibutylphthalate			5.00
Diphenylamine (Added)			(1.00)
Ethyl Alcohol (Residual)	(2.30)	(0.40)	(0.75)
Water (Residual)	(0.70)		(0.50)
Graphite	0.30		
Impetus (MJ/kg)	1.061	1.142	0.912
Flame Temperature (K)	3245.	3695.	2417.
Covolume (m^3/kg)	0.994×10^{-3}	0.962×10^{-3}	1.104×10^{-3}
Ratio of Specific Heats	1.226	1.215	1.259
Molecular Wt. Gases	25.41	26.95	22.06
Grain Length (mm)	10.58	(25.4)	8.26
Grain Diameter (mm)	3.92	(12.7)	3.68
Grain Perf. Diameter (mm)	0.41		0.37
Grain Web (mm)	0.69	0.56	0.64
Grain Geometry	7 Perf	Strip	7 Perf

The experimental program to determine the erosivities of the five propellants consisted of firing each propellant in a 37mm blow-out gun[6-8], and measuring the mass loss of a nozzle which vented the combustion gases. A metal disk was used to contain the pressure in the gun chamber until it ruptured at a specific pressure. The hot combustion gases were then allowed to flow through and erode the contoured nozzle. The thickness of the rupture disk was varied to give three rupture pressures at which erosion measurements were made.

The 37mm blow-out gun used in this study is shown schematically in Figure 3. The blow-out gun consisted of the breech and chamber of a 37mm gun with the barrel cut off just before the forcing cone. A fitting was adapted to the shortened barrel so that a nozzle and rupture disk could be inserted and retained in position. The adaptation of the breech mechanism of the gun is convenient for loading and firing the apparatus. A pressure gage was located mid-chamber to obtain pressure-time data. The nozzle, Figure 4, was a design evolved from earlier blow-out gun firings at the Ballistic Research Laboratory[8-9]. The nozzle was made from SAE 4140 steel and heat treated to have the physical properties of a gun barrel. The rupture disks were punched from 1.54mm (0.060 inch) mild sheet steel. Two disks were used for the first series of firings to obtain a rupture pressure of 193 MPa (28 kpsi), three disks to obtain a pressure of 283 MPa (41 kpsi), and four disks to obtain a pressure of 413 MPa (60 kpsi). Sufficient propellant was used in each test so that at disk rupture about 80 percent of the propellant charge was consumed. An M1B1A2 percussion primer containing 6.5 grams (100 grains) of black powder was used to ignite the propellants. Prior to ignition, the propellant was held about the primer with a paper wad to insure good ignition of the propellant.

In the first series of firings, a separate nozzle was used with each propellant. The nozzles used with M5 and HFP propellants were also activated in a 3mm^2 area, in the entrance of the nozzle, with a beam of 6.125 MeV protons to form a concentration of radioactive cobalt

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6. *J.H. Wiegand, "Erosion in Vent Plugs", Ballistic Research Laboratories Report No. 520, January 1945.*

7. *J.H. Wiegand, "Erosion in Vent Plugs II - The Effect of Vent Shape and of Metal", Ballistic Research Laboratories Report No. 578, January 1946.*

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9. *R.N. Jones and E.R. Weiner, "Experiments on the Erosion of Steel by Propellant Gases Using the Vent Technique", Ballistic Research Laboratories Report No. 1012, March 1957.* (AD #135307)

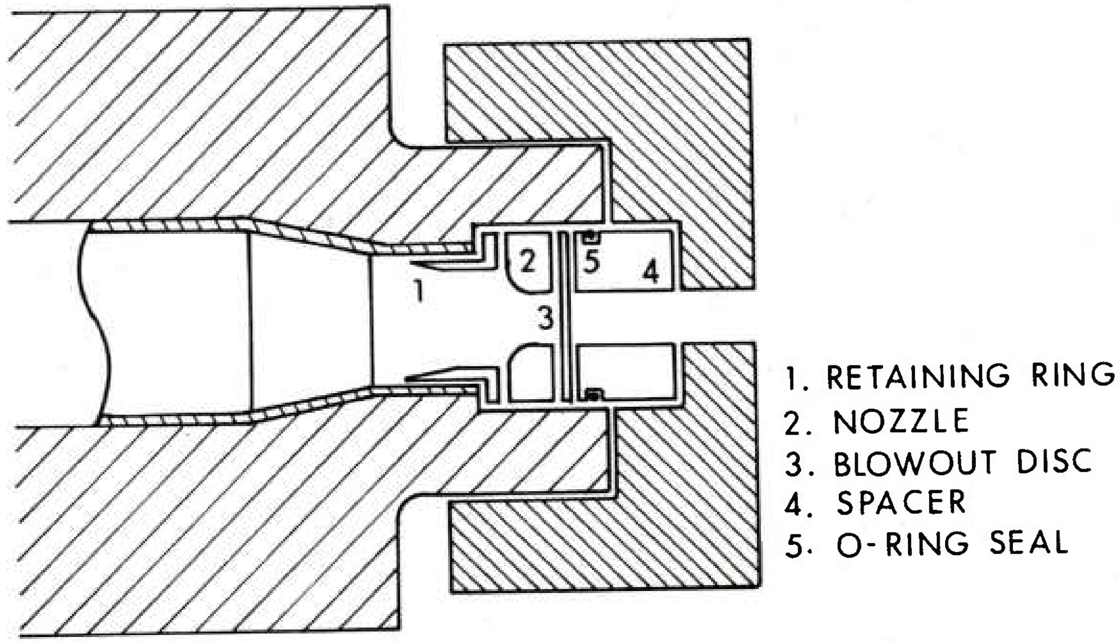

Figure 3. 37mm Blow-Out Gun

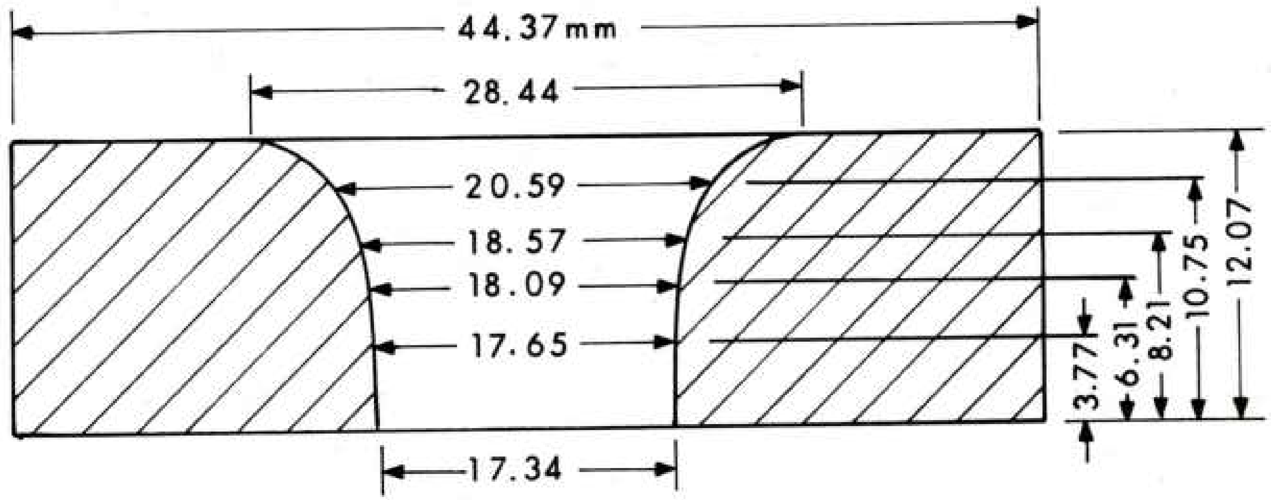

Figure 4. 37mm Blow-Out Gun Contoured Nozzle

by the ^{56}Fe [p,n] ^{56}Co reaction. The depth profile of the tracer has been characterized and therefore the depth of material eroded was determined by a γ-ray counting technique. These two nozzles were used to obtain both mass loss and wear loss where wear loss is a measurement of the depth of nozzle surface eroded. A description of the technique to measure wear in the nozzle and in gun tubes is given in References 10-12.

The five nozzles used in this first series were set aside for Scanning Electron Microscope analysis of the surface. A sixth nozzle was used in subsequent firings.

In the second series of blow-out gun firings, the new nozzle and M5 propellant were used to confirm repeatability of the nozzle mass loss measurements. Following this, a third series of firings was carried out with the same nozzle to determine the effect on nozzle mass loss of cleaning the nozzle surface between shots. In the final series of blow-out gun firings, the sixth nozzle was used to study the effect of higher rupture pressure on nozzle mass loss for the five propellants.

III. RESULTS AND DISCUSSION

The results of the first series of 37mm blow-out gun erosion firings are shown in Table III. In this series, two rupture disks were used which failed at 193 MPa (28 kpsi). The average nozzle mass loss per shot for a series of 12 shots of HFP was 3.1 mg; for M5, 5.0 mg; for M8, 17.7 mg; for M30, 2.9 mg; and for M1, 1.5 mg.

Comparing HFP and M5, propellants with approximately the same flame temperature, the results show the nitramine propellant to be less erosive and thus apparently contradict previous data. Comparing HFP and M8, propellants with high impetus values, M8 is considerably more erosive than HFP. Comparing HFP and M30, where HFP has both a higher flame temperature and impetus than M30, the erosivities and nozzle mass losses are about the same. M1 propellant, having low flame temperature and impetus, gives a low nozzle mass loss as expected.

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10. *R. Birkmire and A. Niiler, "Radioactive Tracers in Erosion Wear Measurements", Proceedings of the Tri-Service Gun Tube Wear and Erosion Symposium, ARRADCOM, Dover, New Jersey, March 1977.*

11. *S.E. Caldwell and A. Niiler, "The Measurement of Wear from Steel Using the Radioactive ^{56}Co", Ballistic Research Laboratories Report No. 1923, September 1976.* (AD #A030262)

12. *A. Niiler and S.E. Caldwell, "The ^{56}Fe [p,n] ^{56}Co Reaction in Steel Wear Measurements", NIM 138, (1976), 179.*

TABLE III. Nozzle Mass Loss as a Function of Shot Number

	Mass Losses[a], mg				
Shot No.	HFP (16)[b]	M5 (17)[b]	M8 (18)[b]	M30 (19)[b]	M1 (20)[b]
1	5.1	5.7	23.1	4.5	2.3
2	2.5	3.9	19.6	3.6	2.1
3	1.6	3.0	12.6	2.8	0.7
4	2.9	4.9	17.2	2.0	2.6
5	3.0	2.7	21.8	3.2	0.9
6	2.9	8.9	15.9	2.2	1.7
7	3.9	4.2	14.3	3.8	2.2
8	3.8	5.7	16.1	2.9	1.2
9	3.2	7.1	16.5	3.3	1.2
10	3.6	4.0	11.9	1.7	1.0
11	2.3	5.2	25.8	2.6	1.4
12	1.9	4.8	17.4	1.8	1.1
Total Mass Loss (mg)	36.7	60.1	212.2	34.4	18.4
Avg. Mass Loss (mg)	3.1	5.0	17.7	2.9	1.5
Std. Deviation (mg)	1.0	1.7	4.2	0.9	0.6
Impetus (MJ/kg)	1.179	1.061	1.142	1.088	0.912
Flame Temperature (K)	3255.	3245.	3695.	3040.	2417.

a - Rupture Pressure 193 MPa (28 kpsi).
b - Nozzle Serial Number.

In the second series, six shots were fired with M5 propellant, cleaning and weighing the nozzle after every shot. The nozzle mass loss was 5.2 mg compared to 5.0 mg from the first series, indicating repeatability for two nozzles.

In the third series, twelve shots were fired with M5 propellant through the sixth nozzle. The nozzle was cleaned and weighed after every fourth shot rather than after every shot. The average mass loss for each four-round set was 13.6 mg, or 3.4 mg/shot compared with 5.0 and 5.2 mg/shot in the first two series. These results indicate that the condition of the nozzle surface prior to firing the propellant does affect the amount of erosion of the nozzle. The nozzle surface just after firing was covered with a wet, black coating, most likely a mixture of carbon, potassium sulfide, and other condensable products of combustion from the primer and propellant. Therefore, erosivity measurements from test fixtures require careful interpretation before comparing the results with data from other experiments.

The fourth series of firings was conducted to study the effect of higher rupture pressure on the erosion of the nozzle. A series of firings was made with three rupture disks which failed at 283 MPa (41 kpsi) and then with four rupture disks which failed at 413 MPa (60 kpsi). The nozzle was washed and weighed after every shot. The nozzle mass loss results for the higher rupture pressures are shown in Table IV.

At the rupture pressure of 283 MPa (41 kpsi), three shots were made with propellants HFP, M8, M30, and M1, and two shots with M5. The nozzle mass loss per shot for HFP was still less than that for M5, 7.1 mg/shot vs. 25.9 mg/shot. The nozzle mass loss for HFP at this higher rupture pressure was now considerably greater than that for M30, 7.1 mg/shot vs. 3.5 mg/shot. At the rupture pressure of 193 MPa (28 kpsi), the nozzle mass losses were about equal for HFP and M30. The nozzle mass loss for M8 was 60.8 mg/shot and for M1 was 0.8 mg/shot.

At the 413 MPa (60 kpsi) rupture pressure, only one shot each was made with HFP, M5, M8, and M30 propellants. The nozzle mass loss per shot for HFP was still less than that for M5, 42.9 mg vs. 116.4 mg. The nozzle mass loss per shot for HFP was greater than that for M30, 42.9 mg vs. 23.8 mg. The nozzle mass loss for M8 was 306.5 mg.

The effect of increased charge weight and higher rupture pressure is marked. The results in Table IV, show that increasing the pressure from 283 MPa (41 kpsi) to 413 MPa (60 kpsi) resulted in increasing the nozzle mass loss per shot for HFP by a factor by six; M5 by more than a factor of four; M8 by a factor of five; and M30 by a factor of seven. Figure 5 shows graphically the effect of propellant flame temperature and disk rupture pressure on nozzle loss. Additional firings must be made to provide additional erositivity data for these propellants at the higher rupture pressures.

TABLE IV. Summary of Nozzle Mass Loss/Shot for Various Charge Weights and Rupture Pressures

Rupture Pressure (MPa)	Rupture Pressure (kpsi)	Mass Loss, mg HFP	M5	M8	M30	M1
193.	28.	3.1	5.0	17.7	2.9	1.5
283.	41.	7.1	25.9	60.8	3.5	0.8
413.	60.	42.9	116.4	306.5	23.8	---
Impetus (MJ/kg)		1.179	1.061	1.142	1.088	0.912
Flame Temperature (K)		3255.	3245.	3695.	3040.	2417.

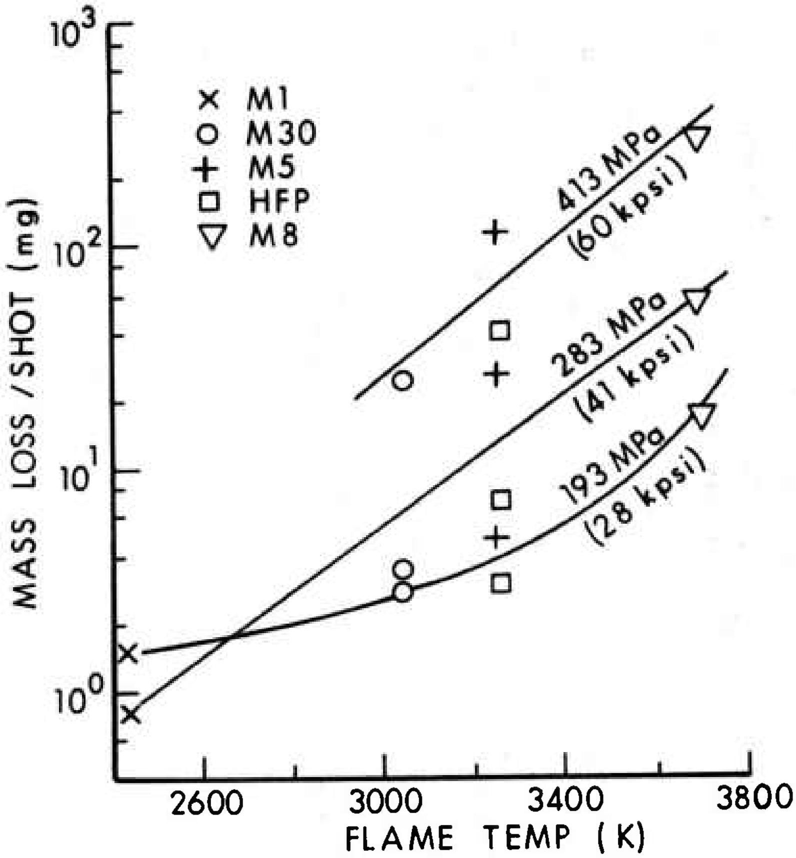

Figure 5. Nozzle Mass Loss vs. Flame Temperature for Various Pressures

The nozzle mass loss results for the HFP nitramine propellant contradict previous results. Generally, it has been reported that propellants containing nitramines are more erosive than the standard Army propellants with comparable flame temperatures[3-5,13]. The procedure used in this study is somewhat different from the ones used in the earlier studies[4,5,13]. In this study, for a given rupture pressure, the time the flowing propellant gases are in contact with the nozzle surface is constant for the five propellants. In the earlier studies, it is not apparent that this time duration was controlled. Table V shows the times the propellant gases are in contact with the nozzle. For a disk rupture pressure of 193 MPa (28 kpsi), the time for depressurization from maximum pressure to 14 MPa (2 kpsi) is about 4.5 ms; for 283 MPa (41 kpsi) about 6.5 ms; and for 413 MPa (60 kpsi) about 7.5 ms. The time from the beginning of pressure rise to maximum pressure is of the same order, varying from 4.5 ms for M8 to 8.3 ms for HFP at the disk rupture pressure of 193 MPa (28 kpsi).

The wear loss results for the two activated nozzles fired with HFP and M5 propellants at a rupture pressure of 193 MPa (28 kpsi) are shown in Table VI. These data are graphically compared with the corresponding nozzle mass loss data in Figure 6. The wear measurements show greater wear with M5 than with HFP, 0.39 microns/shot vs. 0.25 microns/shot. The nozzle mass loss measurements indicate mass loss over the entire nozzle surface whereas the wear loss measurements indicate wear loss from a small area in the nozzle entrance. Comparing the nozzle mass loss to wear loss ratios for the two propellants shows that for M5, the ratio is 12.8 mg/micron, and for HFP, the ratio is 12.4 mg/micron.

IV. CONCLUSIONS

1. Nitramine propellant (HFP) containing 37 percent RDX is no more erosive than a double-base propellant (M5) with a comparable flame temperature.

2. Nitramine propellant (HFP) is less erosive than a double-base propellant (M8) with a comparable impetus.

3. These results contradict previous statements that nitramine propellants are inherently more erosive than conventional gun propellants with equivalent flame temperatures.

4. A correlation between nozzle mass loss and nozzle wear was established by use of a radioactive technique to measure diameter change.

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13. *E.F. Bozza, B.A. Lehman, and R.P. Baumann, "Advanced Nitramine Filled Artillery Propellants", Picatinny Arsenal Technical Memorandum Report No. 2200, May 1976.*

TABLE V. Nozzle Action Time

Propellant	Charge Wt. (Grams)	P_{max} (MPa)	P_{max} (kpsi)	Time to Nozzle Opening (ms)	Flow Duration Time (ms)	Fraction Burned
HFP	54.	193.	28.	8.3	4.4	0.77
	70.	283.	41.	5.8	6.3	0.82
	90.	413.	60.	5.0	7.0	0.86
M5	60.	193.	28.	6.3	4.5	0.77
	77.	283.	41.	5.0	6.4	0.82
	100.	413.	60.	3.6	7.7	0.86
M8	54.	193.	28.	4.5	4.5	0.81
	69.	283.	41.	2.5	6.5	0.88
	100.	413.	60.	2.0	7.4	0.82
M30	58.	193.	28.	6.2	4.5	0.77
	75.	283.	41.	4.2	6.5	0.82
	100.	413.	60.	3.5	7.5	0.83
M1	70.	193.	28.	7.5	4.5	0.74
	86.	283.	41.	7.0	6.5	0.81

TABLE VI. Nozzle Wear Loss Measured by Radioactive Technique

Shot No.	Wear Loss, microns[b] HFP (16)[b]	M5 (17)[b]
1	0.46	0.49
2	0.23	0.27
3	0.42	0.29
4	0.20	0.35
5	0.26	0.27
6	0.10	0.42
7	0.28	0.16
8	0.17	0.49
9	0.17	0.55
10	0.33	0.48
11	0.19	0.33
12	0.15	0.53
Total Wear Loss (microns)	2.96	4.63
Avg. Wear Loss (microns)	0.25	0.39
Std. Deviation (microns)	0.11	0.12
Impetus (MJ/kg)	1.179	1.061
Flame Temperature (K)	3255.	3245.

a - Rupture Pressure 193 MPa (28 kpsi).
b - Nozzle Serial Number.

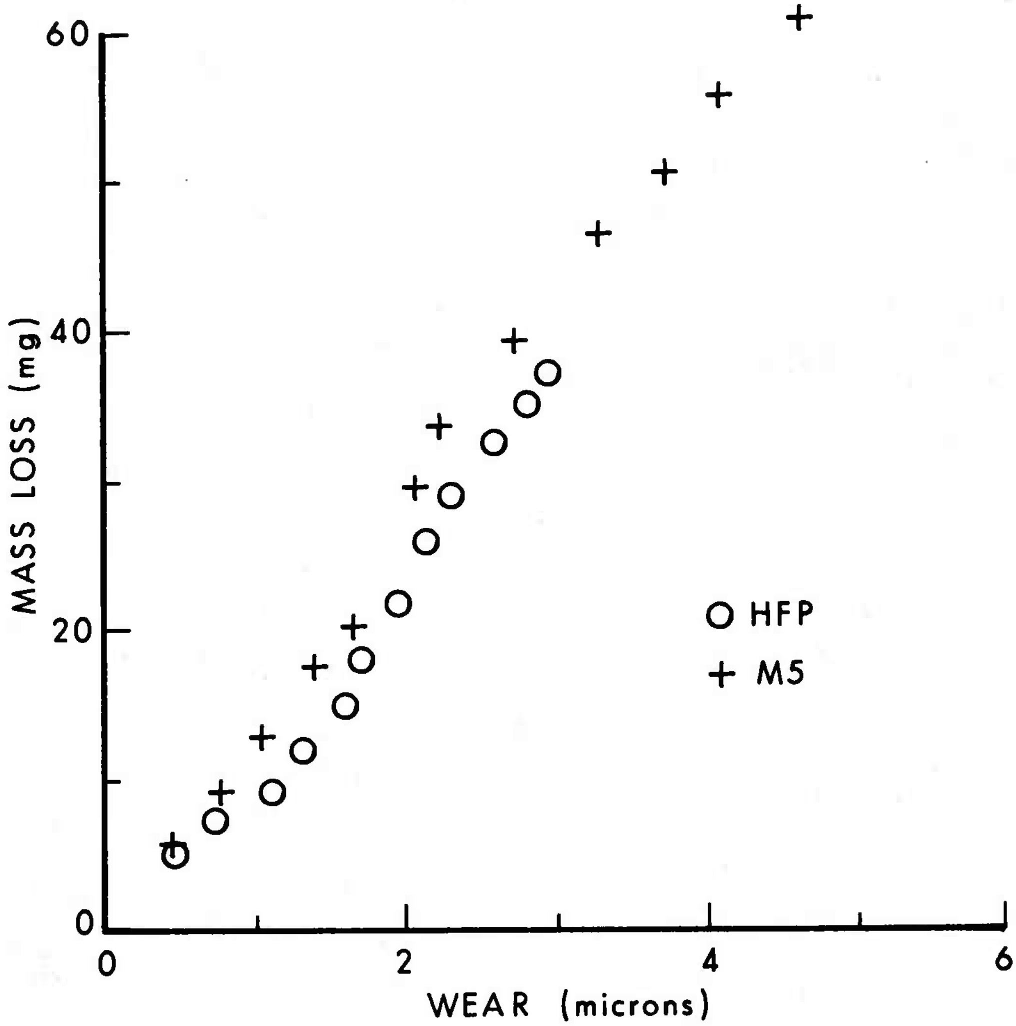

Figure 6. Mass Loss vs. Wear Loss for HFP and M5 Propellants

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